Estimation of radiation doses from short-lived and medium-lived isotopes for the population of the Zhizdra, Uliyanovsk and Khvastovichi rayons of Kaluga region

S.M. Vakulovsky [1],V.I. Balanda[1], T.S. Borodina[1], Yu.S. Tsaturov[2].

[1]State Institution " Research and Production Association "Typhoon"
Russia, 249038,Kaluga region, Obninsk, Pobeda str,4.
[2]Roshydromet, Russia, 123995, Moscow, Novovogankovsky per., 12.

Abstract. Based on experimental and calculation data external radiation doses were estimated for thtree population centres in the Kaluga region. The contribution to the external radiation dose of short-lived and medium-lived isotopes received during the first year after the accident was estimated to be 80 % of the total dose accrued over 15 years and the main contributors are ^{134}Cs, ^{137}Cs, $^{132}Te+^{132}I$.

INTRODUCTION

On 26 April 2011 we marked 25 years after the Chernobyl accident. Over the years since then, data have been obtained by different agencies dealing with the Chernobyl accident consequences to estimate radiation doses for the population, as well as to determine effects of exposure on different population groups. At the same time, contributions to external radiation exposure for the population are estimated using assumptions regarding actual isotope composition in soils of the contaminated population centers. The presented work aims to estimate the contribution of the Chernobyl-origin short-lived and medium-lived isotopes to the external radiation dose of the population based on systematization and analysis of all available experimental and calculation data about the radioactive contamination of the population centers in the Kaluga region

MATERIALS AND METHODS

Analysis of meteorological data showed that the radioactivity originating from the Chernobyl accident arrived in the Kaluga region on 28-29 April 1986 [1]. In May 1986 the survey of the contamination in the Kaluga region was organized and soil samples were collected at 3 points occurring in the worst contaminated areas. Table 1 shows experimental data on the contamination density in these population centers [2] recalculated for the date of arrival of air masses originating from the accident location on the territory of the Kaluga region (Zhizdra- Zhizdra rayon- Kolodyassy and Mileyevo- Khvastovichi rayon)

Table 1. Results of measuring the isotope composition of soil samples, as of the fallout date (29.04.1986)

Population center	Soil contamination density, Ci/km^2					
	^{131}I	^{103}Ru	^{134}Cs	^{137}Cs	$^{95}Zr+^{95}Nb$	$^{140}La+^{140}Ba$
Zhizdra	42,0	10,2	3,7	6,9	0,25	5,6
Mileyevo	51,3	10,2	4,4	8,1	1,0	10,0
Kolodyassy	67,3	15,8	6,0	10,6	1,0	11,0

Since the samples were collected in the Kaluga region 22 days after the radioactivity fallout on the underlying surface, due to radioactive decay the concentrations of short-lived isotopes could not be determined in the samples, however, their contributions should also be taken into account in calculating the external radiation doses for the population. Table 2 includes the studied isotopes and estimated contamination densities.

Table 2. Contamination density for short-lived isotopes as derived by calculations for 29.04.1986, Ci/km^2

Population center	^{106}Ru	^{133}I	$^{132}Te+^{132}I$	^{136}Cs	^{141}Ce	$^{144}Ce+^{144}Pr$	^{125}Sb	^{99}Mo	^{239}Np
Zhizdra	1,5	12,6	131	37	0,29	0,17	0,41	0,3	1,4
Mileyevo	1,8	15,4	161	45	1,17	0,67	0,49	1,2	5,6
Kolodyassy	2,5	20,3	211	59	1,17	0,67	0,64	1,2	5,6

The values for density of contamination with isotopes ^{133}I, $^{132}Te+^{132}I$ and ^{136}Cs were estimated using the ratio of these isotopes to ^{131}I available from experimental data about their concentrations in the air of Moscow on 28-29.04.1986 [3].

The density of area contamination with isotopes ^{99}Mo, ^{141}Ce, $^{144}Ce+^{144}Pr$ and ^{239}Np was estimated using the ratio of these isotopes to ^{95}Zr in the release from the Chernobyl accidental unit [4].

The values of ^{125}Sb and ^{106}Ru contamination density were estimated by the ratio of these isotopes to ^{137}Cs, as described in [5].

The external radiation doses were estimated in accordance with the guidelines [5]. The mean accumulated dose of external radiation in 1986-2001 was estimated for three time intervals: the first year following the Chernobyl accident, the second internal is $1<t\leq 9,7$ years after the accident and the third - $9,7<t<14,7$ years after the accident. For estimating the external radiation doses we identified the groups with different working conditions: group 1 – persons who work outdoors (machine operators, crop growers, agrotechnicians,) and group 2 are those working indoors (salesmen, teachers, accountants etc). The population groups were also distinguished by dwelling conditions (floor, building materials used). Because no statistical data on the population structure and housing properties were available, the calculations were based on using a typical structure of the rural population.

The doses for the first year after the accident were estimated using the following assumptions:

- The contributions of all radionuclides shown in tables 1 and 2 to the external radiation dose for the population were taken into account;
- Due to minor changes in the gamma radiation dose rate in the first months after the accident, account was taken of seasonal variations in the population behavior.

For the first year after the accident the effective dose rate E(t) in the i-group of adults living in k-type houses was estimated by the formula:

$$E(t) = D(t) \cdot k_E \cdot k_C \cdot R(t), \ \mu Sv/day \qquad (1)$$

where D(t) is the absorbed dose rate in the air at the height 1m above the virgin land plot, µGy/day;
k_E is the conversion factor from the absorbed dose in the air to the effective dose in adults, equal to 0.75 µSv/µGy;
k_C is the coefficient accounting for the impact of snow cover on the effective dose, equal to 0.8 for the time period from 1 November to 31 March and equal to 1 for the remaining time of the year, relative units;
R(t) is the factor accounting for the general effect of external radiation dose reduction in the anthropogenic environment for the i-group of the population living in k-type houses. The values of seasonal factors R(t) for the first year after the accident are provided in the guidance [5].

The absorbed dose rate in the air above the virgin soil during the first year after the Chernobyl accident was calculated using the ratio:

$$D^l(t) = 0{,}024 \cdot r(t) \cdot \sigma^l \cdot d^l \cdot \exp(-\lambda_l \cdot t), \quad \mu Gy/day \qquad (2)$$

where: r(t) is the function accounting for the effect of soil migration of radionuclides on the air absorbed dose rate and equal to the ratio of the dose rate at the time moment *t* above soil, with known distribution of nuclides in soil, to the dose rate d^l due to a thin source occurring on the air-soil interface;
σ^l is the mean soil contamination density with the lst radionuclide in the population center, as of the date of ending of radioactive fallout, kBq/m^2;
d^l is the specific absorbed dose rate in the air due to gamma radiation of the 1^{st} radionuclide for the geometry of a thin isotope source occurring on the air-soil interface, $(nGy/hour)/(kBq/m^2)$ (provided in [5]);
λ_l is the radioactive decay constant for the 1^{st} radionuclide, day^{-1};
t is the time since the radioactive fallout in the population center, days.

The accumulated effective external dose for the adult population during the first year after the accident was estimated for each isotope using the formula:

$$E(t) = k_E \times (R^I (D(0) \times (t_1 - t_0)/2 + \int_0^{189-t_1} D(t)dt + R^{II} \times k_C \times \int_{189-t_1}^{340-t_1} D(t)dt + R^{III} \int_{340-t_1}^{365} D(t)dt$$

, µSv (3)

where D(t) is determined by equation (2);
t_0 is the time from the accident (26.04.86) to the beginning of radioactive fallout, days;
t_1 is the time from the accident to the time of maximum contamination density, days;
R^I, R^{II}, R^{III} are the values of seasonal factors for a typical population structure for the first year after the accident, as provided in [5].

Results of the calculations are provided in table 3.

Table 3. Accumulated effective external radiation dose accrued by the population over the 1st year after the accident, μSv

Isotope	Population center			Isotope contribution to total dose, % (*)
	Zhizdra	Mileyevo	Kolodyassy	
^{131}I	153	187	245	3
^{103}Ru	262	262	407	5
^{134}Cs	1350	1612	2212	25
^{137}Cs	1078	1266	1657	19
$^{95}Zr+^{95}Nb$	15	61	61	1
$^{140}La+^{140}Ba$	83	146	160	2
^{106}Ru	124	146	191	2
^{133}I	5,7	6,9	9,1	-
$^{132}Te+^{132}I$	1040	1271	1667	19
^{136}Cs	1226	1499	1966	23
^{141}Ce	0,03	0,12	0,12	-
$^{144}Ce+^{144}Pr$	1,7	7,0	7,0	-
^{125}Sb	50	58	76	1
^{99}Mo	0,01	0,03	0,03	-
^{239}Np	0,01	0,05	0,05	-
Total for all isotopes	5389	6522	8658	
Total for short-lived isotopes	4310	5256	7001	
Contribution of short-lived isotopes to dose %	80	81	81	

*Estimates of contributions of separate isotopes to the total external radiation dose practically did not change for all three population centers

In calculating the doses for the second time interval (1<t≤9.7 years after the accident) and the third time interval (9.7<t<14.7 years after the accident) the following assumptions were used:

- Only the contributions of ^{134}Cs and ^{137}Cs to the external radiation dose were taken into account, as the contributions of other radionuclides can be neglected;
- Due to slow changes in the dose rate with time the mean annual values of the behavior factors were used.

For the second time interval (1-9.7 years) the accumulated effective external dose rate in the i-group of adults living in k-type houses was estimated by the formula:

$$E(t) = k_E \times k_C \times R_{ik} \times \int_{365}^{9,7\times 365} D(t)\,dt, \quad \mu Sv$$

(4)

where D(t) is determined by equation (2), and the values of R_{ik} are those for a typical population structure [5].
Results of calculating the accumulated external radiation dose for the time period (1-9.7 years after the accident) are shown in table 4.

Table 4. Radiation dose accrued by the population over the second time interval (1-9.7 years after the accident), µSv

Isotope	Population center		
	Zhizdra	Mileyevo	Kolodyassy
^{134}Cs	1605	1917	2631
^{137}Cs	3918	4599	6019

The accumulated external radiation dose in the third time interval (9.7-14.7 years after the accident) is estimated by the formula:

$$E(t) = 0{,}8 \times k_E \times k_C \times R_{ik} \times \int_{9,7\times 365}^{14,7\times 365} D(t)\,dt, \quad \mu Sv$$

(5)

Table 5 shows results of estimating the accumulated external radiation dose in the time period 9.7-14.7 years after the accident.

Table 5. Radiation dose accrued by the population over the third time interval (9.7- 14.7 years after the accident), µSv

Isotope	Population center		
	Zhizdra	Mileyevo	Kolodyassy
^{134}Cs	38	45	62
^{137}Cs	1085	1274	1667
Contribution of ^{134}Cs to dose, %	3,4	2,9	2,2

CONCLUSION.

The obtained results lead us to conclude that the contributions of short and medium-lived isotopes to the external radiation dose during the second and third time periods are 40% and 37%, respectively. The contribution of ^{134}Cs to the external radiation dose in the third period was 2-3%. This suggests that when estimating the external radiation doses for the time more than 15 years after the Chernobyl accident, only ^{137}Cs radiation should be taken into account. Unfortunately, for the early period after the accident the archives of Kaluga region contamination data contain data for two rayons only: Zhizdra and Khvastovichi. Considering that the contributions of short and medium-lived isotopes in the population centers located in these two rayons do not differ much, it may be assumed that these isotopes will make same contribution in

Uliyanovsky rayon and other rayons of the Kaluga region affected by the Chernobyl accident

Acknowledgement

The research has been supported within the RFFR project №05-05-96714.

References

1. M.Yu. Orlov, V.P.Snykov, Yu.A. Khvalensky. Temporal and spatial characteristics of radioactive contamination of the Kaluga region after the Chernobyl accident //Legacy of Chernobyl. Issue 2. Kaluga, Obninsk, 1996, p. 41-46.
2. M.Yu. Orlov, V.P.Snykov, Yu.A. Khvalensky, V.P.Teslenko, A.I.Korenev. Radioactive contamination of the territory of Belarus and Russia after the Chernobyl accident //Atomic energy, v.72, issue 4, 1992, p.371-376.
3. A.S. Zykova, E.L.Telushkina, T.F.Voronina. The radiation situation in Moscow in connection with the Chernobyl accident on 26 April 1986. //Short-term and long-term consequences of the Chernobyl accident. Moscow, 1987, p.176-184.
4. Yu.A. Izrael, S.M.Vakulovsky, V.A. Vetrov, V.N. Petrov, F.Ya. Rovinsky, E.D.Stukin Chernobyl: radioactive contamination of the environmental media. Leningrad, Hydrometeoizdat , 1990, 296 p.
5. Reconstruction of the mean effective radiation dose accrued by the population in 1986-2001 in the population centers of the Russian Federation exposed to contamination as a result of the Chernobyl accident in 1986 // Guidance 2.6.1.1114-02. Ministry of Health Care of RF, Moscow, 2002